Lake Michigan Committee
March 23, 2010

Status and Trends of Prey Fish Populations in Lake Michigan, 2009[1]

Charles P. Madenjian, David B. Bunnell, Jeffrey D. Holuszko, Timothy J. Desorcie, and Jean V. Adams
U. S. Geological Survey
Great Lakes Science Center
1451 Green Road
Ann Arbor, Michigan 48105

Abstract

The Great Lakes Science Center (GLSC) has conducted lake-wide surveys of the fish community in Lake Michigan each fall since 1973 using standard 12-m bottom trawls towed along contour at depths of 9 to 110 m at each of seven index transects. The resulting data on relative abundance, size structure, and condition of individual fishes are used to estimate various population parameters that are in turn used by state and tribal agencies in managing Lake Michigan fish stocks. All seven established index transects of the survey were completed in 2009. The survey provides relative abundance and biomass estimates between the 5-m and 114-m depth contours of the lake (herein, lake-wide) for prey fish populations, as well as burbot, yellow perch, and the introduced dreissenid mussels. Lake-wide biomass of alewives in 2009 was estimated at 13.03 kilotonnes (kt) (1 kt = 1000 metric tons), which was more than double the 2008 estimate. Lake-wide biomass of bloater in 2009 was estimated at 6.98 kt, which was nearly three times higher than the 2008 estimate. Rainbow smelt lake-wide biomass equaled 1.26 kt in 2009, which was nearly double the 2008 estimate. Deepwater sculpin lake-wide biomass equaled 3.73 kt, which was only 4% lower than the 2008 estimate. Nevertheless, the 2009 estimate was the lowest value in the deepwater sculpin time series. Slimy sculpin lake-wide biomass remained relatively high in 2009 (3.59 kt), increasing 72% over the 2008 level. Ninespine stickleback lake-wide biomass equaled 0.39 kt in 2008, which was nearly identical to the 2008 estimate. The final prey fish, exotic round goby, decreased by 83% between 2008 and 2009, from 3.76 to 0.63 kt. Burbot lake-wide biomass (0.90 kt in 2009) has remained fairly constant since 2002. Numeric density of age-0 yellow perch (i.e., < 100 mm) equaled 38 fish per ha, which is indicative of a relatively strong year-class. Lake-wide biomass estimates of dreissenid mussels increased by more than fivefold from 7.57 kt in 2008 to 40.79 kt in 2009. Overall, the total lake-wide prey fish biomass estimate (sum of alewife, bloater, rainbow smelt, deepwater sculpin, slimy sculpin, round goby, and ninespine stickleback) in 2009 was 29.62 kt, which represented a 52% increase over the 2008 estimate.

[1] Presented at: Great Lakes Fishery Commission
Lake Michigan Committee Meeting
Windsor, ON
March 23, 2010

The Great Lakes Science Center (GLSC) has conducted daytime bottom trawl surveys in Lake Michigan during the fall annually since 1973. From these surveys, the relative abundance of the prey fish populations are measured, and estimates of lake-wide biomass available to the bottom trawls (for the region of the main basin between the 5-m and 114-m depth contours) can be generated (Hatch et al. 1981; Brown and Stedman 1995). Such estimates are critical to fisheries managers making decisions on stocking and harvest rates of salmonines and allowable harvests of fish by commercial fishing operations.

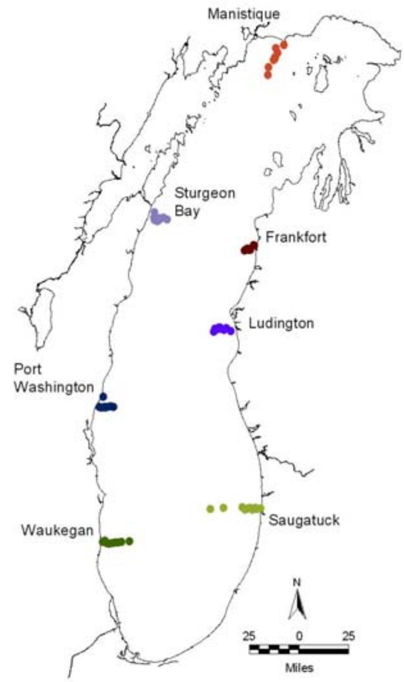

Figure 1. Established sampling locations for GLSC bottom trawls in Lake Michigan.

The basic unit of sampling in our surveys is a 10-minute tow using a bottom trawl (12-m headrope) dragged on contour at 9-m (5 fathom) depth increments. At most survey locations, towing depths range from 9 or 18 m to 110 m. Age determinations are performed on alewives (*Alosa pseudoharengus*, using otoliths) and bloaters (*Coregonus hoyi*, using scales) from our bottom trawl catches (Madenjian et al. 2003; Bunnell et al. 2006a). Although our surveys have included as many as nine index transects in any given year, we have consistently conducted the surveys at seven transects. These transects are situated off Manistique, Frankfort, Ludington, and Saugatuck, Michigan; Waukegan, Illinois; and Port Washington and Sturgeon Bay, Wisconsin (Figure 1). All seven transects were completed in 2009.

Lake-wide estimates of fish biomass require (1) accurate measures of the surface areas that represent the depths sampled and (2) reliable measures of bottom area swept by the trawl. A complete Geographical Information System (GIS) based on depth soundings at 2-km intervals in Lake Michigan was developed as part of the acoustics study performed by Argyle et al. (1998). This GIS database was used to estimate the surface area for each individual depth zone surveyed by the bottom trawls. Trawl mensuration gear that monitored net configuration during deployment revealed that fishing depth (D, in meters) influenced the bottom area swept by the trawl. Since 1998, we had corrected the width (W, in meters) of the area sampled according to $W = 9.693 - (43.93/D)$, as well as the actual time (AT, in minutes) spent on the bottom according to $AT = \text{tow time} - 3.875 + D^{0.412}$ (Fleischer et al. 1999; Figure 2). These relationships, along with boat speed, had been used to estimate bottom area swept. However, we recently discovered that the tow speed used in deriving these relationships in 1998 was substantially greater than the tow speed normally used during our bottom trawl survey. Consequently, we used trawl mensuration gear during June 2009 to characterize the bottom trawl net configuration during deployment at

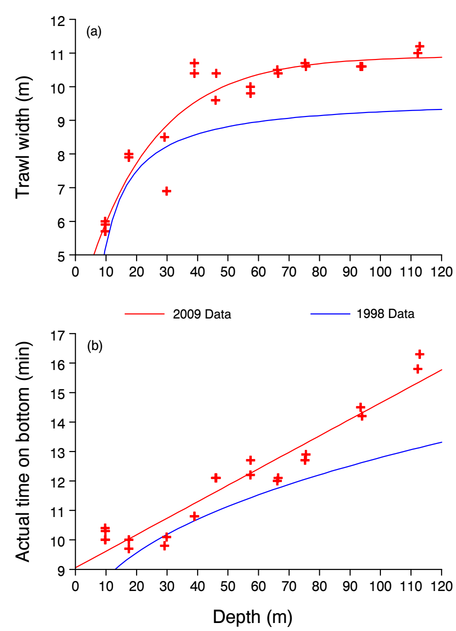

Figure 2. Bottom trawl width (a) and actual time on bottom (b) as a function of bottom depth. Actual time on bottom is shown for a 10-minute tow.

the tow speed regularly used during the survey. Results showed that at the normal tow speed, the net width was about 20% greater than net width when the faster tow speed had been used in 1998 (Figure 2a). In addition, AT at the normal tow speed was greater than AT at the faster tow speed (Figure 2b). Thus, we had been overestimating density and biomass by roughly 20%, according to our trawl measurements. For this report, all densities and lake-wide biomasses were calculated using the new relationships $W = 3.232 + 7.678(1 - e^{-0.044*D})$ and AT = tow time – 0.945 + (0.056D) derived from the trawl measurements made during June 2009.

To facilitate comparisons of our estimates of fish abundance with abundance estimates in other lakes and with hydroacoustic estimates of abundance, we report both numeric (fish per hectare [ha]) and biomass (kg per ha) density. A weighted mean density over the entire range of depths sampled (within the 5-m to 114-m depth contours) was estimated by first calculating mean density for each depth zone, and then weighting mean density for each depth zone by the proportion of lake surface area assigned to that depth zone. Standard error (SE) of mean density was estimated by weighting the variances of fish density in each of the depth zones by the appropriate weight (squared proportion of surface area in the depth zone), averaging the weighted variances over all depth zones, and taking the square root of the result. Relative standard error (RSE) was calculated by dividing SE by mean fish density and multiplying this ratio by 100 to yield a percentage. SE and RSE for the estimate of lake-wide biomass were calculated in a manner analogous to that for calculating SE and RSE for the estimate of mean numeric or biomass density. For this report, we provide plots of prey fish RSE for numeric density only, as RSE for biomass density exhibited a similar trend.

NUMERIC AND BIOMASS DENSITY

By convention, we classify "adult" prey fish as age 1 or older, based on length-frequency: alewives ≥ 100 mm total length (TL), rainbow smelt (*Osmerus mordax*) ≥ 90 mm TL, bloaters ≥ 120 mm TL, and yellow perch (*Perca flavescens*) ≥ 100 mm TL. We assume all fish smaller than the above length cut-offs are age-0. Catches of age-0 alewife, bloater, and rainbow smelt are not necessarily reliable indicators of future year-class strengths for these populations, because their small size and position in the water column make them less vulnerable to bottom trawls. Nevertheless, during the bloater recovery in Lake Michigan that began in the late 1970s, our survey contained unusually high numbers of age-0 bloaters, indicating some correspondence between bottom trawl catches and age-0 abundance in the lake. Catch of age-0 yellow perch is likely a good indicator of year-class strength, given that large catches in the bottom trawl during the 1980s corresponded to the strong yellow perch fishery.

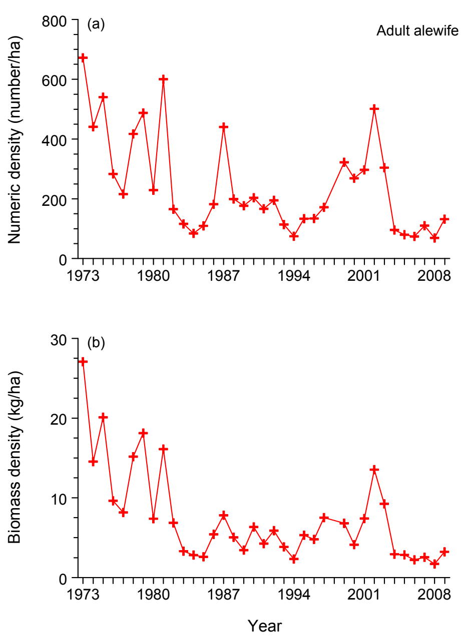

Figure 3. Density of adult alewives as number (a) and biomass (b) per ha in Lake Michigan, 1973-2009.

Alewife – Since its establishment in the 1950s, the alewife has become a key member of the fish community. As a larval predator, adult alewife can depress recruitment of native fishes, including burbot (*Lota lota*), deepwater sculpin (*Myoxocephalus thompsonii*), emerald shiner (*Notropis atherinioides*), lake trout (*Salvelinus namaycush*), and yellow perch (Smith 1970; Wells and McLain 1973; Madenjian et al. 2005b, 2008; Bunnell et al. 2006b). Additionally, alewife has remained the most important constituent of salmonine diet in Lake Michigan for the last 35 years (Jude et al. 1987; Stewart and Ibarra 1991;

Warner et al. 2008). Most of the alewives consumed by salmonines in Lake Michigan are eaten by Chinook salmon (*Oncorhynchus tshawytscha*, Madenjian et al. 2002). A commercial harvest was established in Wisconsin waters of Lake Michigan in the 1960s to make use of the then extremely abundant alewife that had become a nuisance and health hazard along the lakeshore. In 1986, a quota was implemented, and as a result of these rule changes and seasonal and area restrictions, the estimated annual alewife harvest declined from about 7,600 metric tons in 1985 to an incidental harvest of only 12 metric tons after 1990 (Mike Toneys, Wisconsin Department of Natural Resources, Sturgeon Bay, personnel communication). There is presently no commercial fishery for alewives in Lake Michigan.

Adult alewife biomass density increased from 1.7 kg per ha in 2008 to 3.2 kg per ha in 2009 (Figure 3b). This increase was likely due to both a slight lessening of the degree of predation on alewives by the Chinook salmon population in the lake and the 2005 year-class of alewives becoming fully recruited to the bottom trawl. The 2005 year-class, although not nearly as strong as the 1998 year-class, appeared to be a relatively large one. In addition, based on angler catch rate, Chinook salmon abundance in Lake Michigan decreased between 2008 and 2009 (R. Claramunt, Michigan Department of Natural Resources, personal communication), and this decrease in Chinook salmon abundance may have been of sufficient proportion to significantly reduce the amount of predation on alewives by Chinook salmon. Mimicking the temporal pattern in biomass density, numeric density of adult alewives increased by nearly a factor of two between 2008 and 2009 (Fig. 3a). The overall temporal trends in adult alewife density primarily reflected an increase in predation by salmonines on alewives during the 1970s and 1980s, followed by relatively high predation maintained by salmonines on alewives from the early 1980s to the present time (Madenjian et al. 2002, 2005a).

During 1973-2009, RSE for adult alewife numeric density averaged 24% (Figure 4a). RSE has generally increased during 1999-2009 (mean= 38%) relative to earlier years (mean=19%) which suggested that adult alewives are more patchily distributed in recent years than in earlier ones.

The catch of adult alewives was dominated by fish of ages 2-4 in 2009 (Figure 5). Age-4 (2005 year-

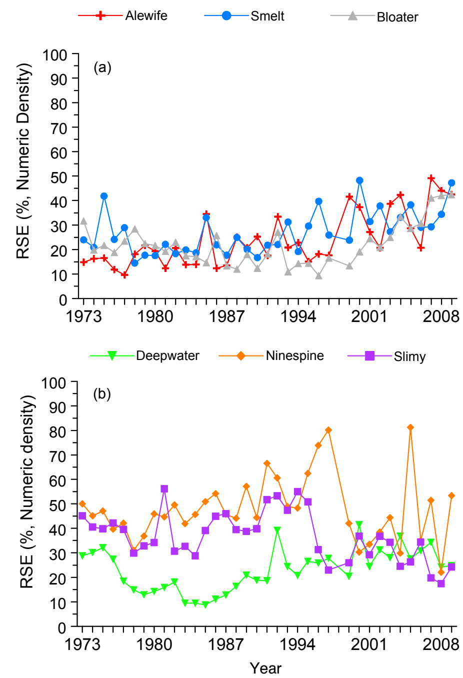

Figure 4. RSE for numeric density of Lake Michigan prey fishes, 1973-2009. Panel (a) provides estimates for adult alewife, adult rainbow smelt, and adult bloater. Panel (b) provides estimates for deepwater sculpin, slimy sculpin, and ninespine stickleback.

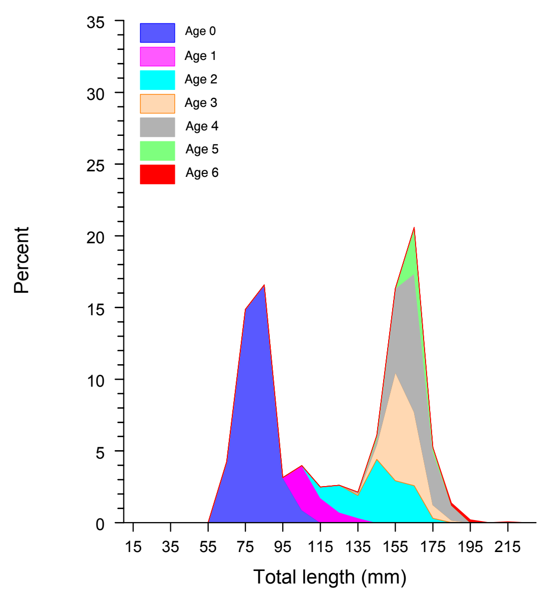

Figure 5. Age-length distribution of alewives caught in bottom trawls in Lake Michigan, 2009.

class) fish accounted for 34% of the adult catch, by number of fish. Age-2 (2007 year-class) and age-3 (2006 year-class) represented 24% and 25%, respectively, of the adult catch.

Our results for recent temporal trends in adult alewife density were in accord with results from the acoustic survey. Warner et al. (2010) reported adult alewife biomass increased by more than a factor of two between 2008 and 2009. This agreement between gear provided further support for the contention that a slight decrease in the predation effect exerted by Chinook salmon on alewives was at least partly responsible for the observed increase in adult alewife abundance.

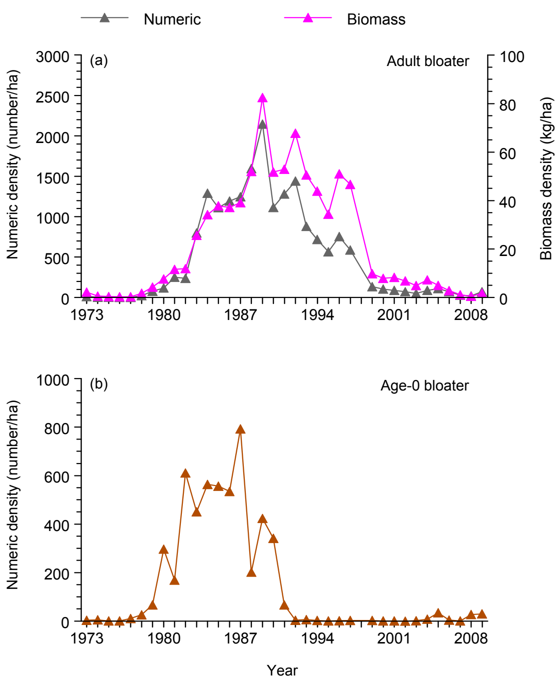

Figure 6. Panel (a) depicts numeric and biomass density of adult bloater in Lake Michigan, 1973-2009. Panel (b) depicts numeric density of age-0 bloater in Lake Michigan, 1973-2009.

Bloater - Bloaters are eaten by salmonines in Lake Michigan, but are far less prevalent in salmonine diets than alewives (Warner et al. 2008). Over 30% of the diet of large (≥ 600 mm) lake trout at Saugatuck and on Sheboygan Reef was composed of adult bloaters during 1994-1995, although adult bloaters were a minor component of lake trout diet at Sturgeon Bay (Madenjian et al. 1998). When available, juvenile bloaters have been a substantial component of salmon and nearshore lake trout diets, particularly for intermediate-sized fish (Elliott 1993; Rybicki and Clapp 1996). The bloater population in Lake Michigan also supports a valuable commercial fishery.

Biomass density of adult bloater increased by more than threefold between 2008 (0.5 kg per ha) and 2009 (1.8 kg per ha) (Figure 6a). Similarly, adult bloater numeric density increased from 21 fish per ha in 2008 to 72 fish per ha in 2009. RSE for adult bloater numeric density has averaged 22% during 1973-2009, but RSE for 2009 was 42% following a general trend of increasing RSE since 1999 (Figure 4a).

Adult bloater numeric and biomass densities have shown an overall declining trend since 1989 (Figure 6a). These declines are attributable to relatively poor recruitment since 1992 (Madenjian et al. 2002, Bunnell et al. 2006a, Bunnell et al. 2009a). Recent work investigated whether a reduction in size-specific fecundity (owing to lower observed condition with the decline of *Diporeia* spp.) could be responsible for poor recruitment (Bunnell et al. 2009a). Although fecundity in 2006 was 24% lower than in the late 1960s (when adult condition was 69% higher), this reduction does not explain why bloater recruitment has been so consistently low.

Madenjian et al. (2002) proposed that the Lake Michigan bloater population may be cycling in abundance, with a period of about 30 years. There are signs of modest increases in recruitment in recent years. Numeric density of age-0 bloaters (< 120 mm TL) in 2005, 2008, and 2009 were 34, 27, and 29 fish per ha, respectively (Figure 6b). Although these densities pale in comparison to those observed between 1980 and 1990 (mean = 449 fish per ha), they are an order of magnitude greater than all of the other densities since 1992 (mean = 2 fish per ha). The observed increase in adult bloater biomass density between 2008 and 2009 was likely attributable, at least in part, to the 2005 year-class recruiting to the adult population. Bloaters do not fully recruit to the bottom trawl until age 3 or age 4 (Bunnell et al. 2006a). The observed increase in adult bloater numeric density between 2008 and 2009 was probably due, at least in part, to the 2008 year-class beginning to recruit to the adult population. Thus, the 2009 bottom trawl data indicated a link between the recent modest increases in age-0 bloater abundance and a subsequent increase in adult bloater abundance.

The bloater population in Lake Michigan during 2009 appeared to be very young, as 47% of the trawl catch was represented by age-1 fish and 38% of the catch was represented by age-2 fish. The percentage of age-4 and older bloater in the trawl catch was only 9% in 2009. Given the recent modest increases in recruitment, a young bloater population would be expected.

Results from the acoustic survey indicated that bloater biomass decreased between 2008 and 2009 (Warner 2010). However, this decrease in biomass was a result of a decrease in the size of small bloater. Numeric density actually increased slightly between 2008 and 2009, but juvenile bloaters were very small compared with previous years. Thus, the bottom trawl survey results were in agreement with the acoustic survey results with regard to this recent increase in bloater abundance. A similar pattern has been observed in Lake Huron acoustic and bottom trawl survey results, which is consistent with the findings of Madenjian et al. (2008) and Bunnell et al. (2010), who observed broad-scale, long-term synchrony between bloater populations in Lake Michigan and Lake Huron.

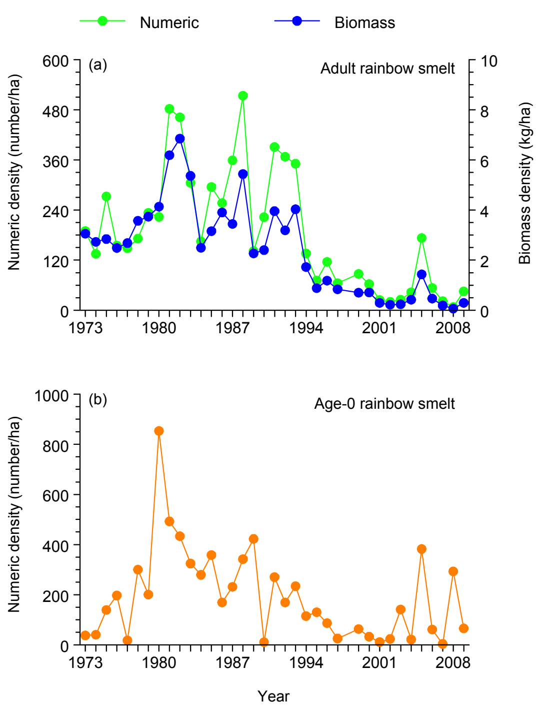

Figure 7. Panel (a) depicts numeric and biomass density of adult rainbow smelt in Lake Michigan, 1973-2009. Panel (b) depicts numeric density of age-0 rainbow smelt in Lake Michigan, 1973-2009.

Rainbow smelt – Adult rainbow smelt is an important diet constituent for intermediate-sized (400 to 600 mm) lake trout in the nearshore waters of Lake Michigan (Stewart et al. 1983; Madenjian et al. 1998). Overall, however, rainbow smelt are not eaten by Lake Michigan salmonines to the same extent as alewives. The rainbow smelt population supports commercial fisheries in Wisconsin and Michigan waters (Belonger et al. 1998; P. Schneeberger, Michigan Department of Natural Resources, Marquette, MI, personal communication).

Adult rainbow smelt biomass density increased from 0.07 kg per ha in 2008, the year of the lowest adult biomass density for adult rainbow smelt, to 0.30 kg per ha in 2009 (Figure 7a). Despite this more than threefold increase between 2008 and 2009, the 2009 level still represented a relatively low value in the time series. Adult rainbow smelt numeric density increased from 8 fish per ha in 2008 to 45 fish per ha in 2009. But, again, this 2009 level was a relatively low value in the time series. Adult rainbow smelt numeric density was highest from 1981 to 1993, but then declined between 1993 and 2001, and has remained at a relatively low density, except in 2005, since 2001. Causes for the decline remain unclear. Consumption of rainbow smelt by salmonines was higher in the mid 1980s than during the 1990s (Madenjian et al. 2002), yet adult and age-0 (< 90 mm TL) rainbow smelt abundance remained high during the 1980s (Figure 7b). Age-0 rainbow smelt has been highly variable since 2002. Age-0 numeric density in 2009 was 66 fish per ha, which was considerably lower than the average density for the entire time series of 194 fish per ha. RSE for adult rainbow smelt numeric density averaged 27% from 1973-2009, and RSE for 2009 was 47% (Figure 4a).

Temporal trends in rainbow smelt biomass from the acoustic and bottom trawl surveys have been somewhat similar since 2002. The bottom trawl survey has documented generally declining biomass estimates since 2002, except for 2004-2006 when smelt biomass increased to a relatively high level in 2005 but then fell back to low levels after 2006. Similarly, biomass of rainbow smelt in the acoustic survey increased considerably in 2005 and 2006 before appearance of a decreasing trend from 2007 to 2009 (Warner et al. 2010). The acoustic survey revealed rainbow smelt biomass in 2008 to be only 10% of the average biomass attained during the 1990s.

Sculpins – From a biomass perspective, the cottid populations in Lake Michigan proper have been dominated by deepwater sculpins, and to a lesser degree, slimy sculpins (*Cottus cognatus*). Spoonhead sculpins (*Cottus ricei*), once fairly common, suffered declines to become rare to absent by the mid 1970s (Eck and Wells 1987). Spoonhead sculpins are still encountered in Lake Michigan, but in small numbers (Potter and Fleischer 1992).

Slimy sculpin is a favored prey of juvenile lake trout in nearshore regions of the lake (Stewart et al. 1983; Madenjian et al. 1998), but is only a minor part of adult lake trout diets. Deepwater sculpin is an important diet constituent for burbot in Lake Michigan, especially in deeper waters (Van Oosten and Deason 1938; Brown and Stedman 1995; Fratt et al. 1997).

Numeric density of deepwater sculpins in Lake Michigan was only 92 fish per ha in 2009, which was the lowest value in the time series (Figure 8a). Likewise, biomass density of deepwater sculpins in Lake Michigan was only 1.1 kg per ha, the lowest value in the time series. During 1990-2006, both deepwater sculpin biomass density and numeric density trended neither downward nor upward. However, deepwater sculpin catch in our bottom trawls dropped suddenly and drastically during 2007-2009. Madenjian and Bunnell (2008) demonstrated that deepwater sculpins have been captured at increasingly greater depths since the 1980s. Therefore, one potential explanation for the recent declines in deepwater sculpin densities is that an increasing proportion of the population is now occupying depths deeper than those sampled by our survey (i.e., 110 m). Furthermore, because the deepwater sculpin occupies deeper depths than any of the other prey fishes of Lake Michigan, a shift to waters deeper than 110 m would seem to be a reasonable explanation for the recent declines in deepwater sculpin densities. Previous analysis of the time series indicated deepwater sculpin density is negatively influenced by alewife (predation on sculpin larvae) and burbot (predation on juvenile and adult sculpin, Madenjian et al. 2005b). Neither alewife nor burbot have increased in recent years to account for this decline in deepwater sculpins. Which factor or factors could have driven the bulk of the deepwater sculpin population to move to waters deeper than 110 m during 2007-2009? This proposed shift to deeper water by deepwater sculpins coincided with the population explosion of the profundal form of the quagga mussel (*Dreissena bugensis*) in Lake Michigan waters of depths between 60 and 90 m (Bunnell et al. 2009b; T. Nalepa, NOAA Great Lakes Environmental Research Laboratory, personal communication). Perhaps some consequences of the colonization of deeper waters by quagga mussels prompted a move of deepwater sculpins to deeper water. If this hypothesis were correct, then a substantial decline in quagga mussel abundance in the 60-m to 90-m deep waters could lead to a shift of deepwater sculpins back to shallower waters. RSE for deepwater sculpin numeric density was 25% in 2009, close to the average of 23% for the entire time series (Figure 4b).

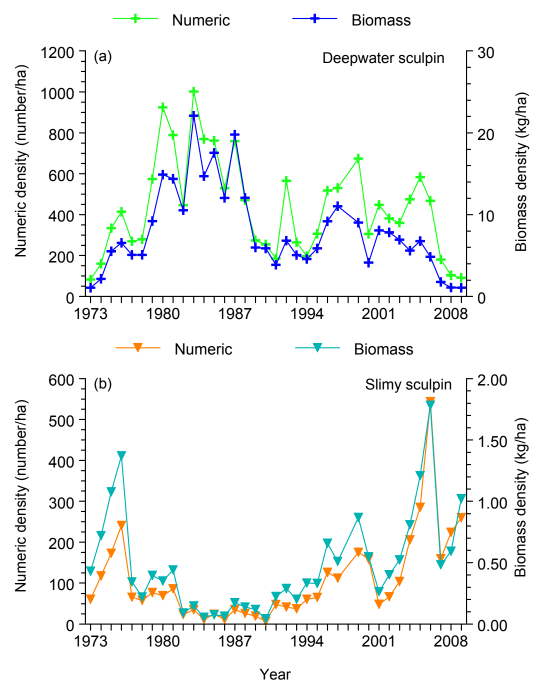

Figure 8. Numeric and biomass density for deepwater (a) and slimy sculpin (b) in Lake Michigan, 1973-2009.

Numeric density of slimy sculpins in Lake Michigan increased from 224 fish per ha in 2008 to 260 fish per ha in 2009, which represented a 16% increase (Figure 8b). Biomass density of slimy sculpins increased from 0.59 kg per ha in 2008 to 1.02 kg per ha in 2009, which represented a 72% increase. RSE for slimy sculpin numeric density was 24% in 2009, which was lower than its average RSE of 37% from 1973-2009 (Figure 4b). Overall, slimy sculpin numeric density has generally increased since around 1990, with considerable interannual variation. This increase was likely attributable to greater emphasis on stocking lake trout on offshore reefs beginning in 1986 (Madenjian et al. 2002). *Diporeia* has dominated the diet of slimy sculpins in Lake Michigan since the 1970s (Madenjian et al. 2002), and *Diporeia* abundance in Lake Michigan has declined during the 1990s and 2000s (Nalepa et al. 2006). To date, this decrease in *Diporeia* abundance does not appear to have had a negative effect on slimy sculpin abundance in Lake Michigan.

Ninespine stickleback – Two stickleback species occur in Lake Michigan. Ninespine stickleback (*Pungitius pungitius*) is native, whereas threespine stickleback (*Gasterosteus aculeatus*) is non-native and was first collected in the GLSC bottom trawl survey during 1984 (Stedman and Bowen 1985). Ninespine stickleback is generally captured in greater densities than the threespine, especially in recent years. Relative to other prey fishes, ninespine sticklebacks are of minor importance to lake trout and other salmonines. In northern Lake Michigan, for example, sticklebacks occur infrequently in the diet of lake trout (Elliott et al. 1996). Numeric density of ninespine stickleback remained fairly low from 1973-1995 (Figure 9a). Densities increased dramatically in 1996-1997, and have since been highly variable. Numeric density of ninespine stickleback was only 63 fish per ha in 2009. Similarly, biomass density was only 0.11 kg per ha in 2009. RSE for ninespine stickleback numeric density was 53% in 2009, which was similar to the long-term average RSE of 48% from 1973-2009 (Figure 4b). A recent analysis of ninespine stickleback densities in lakes Michigan and Superior revealed that the recent increase in Lake Michigan coincided with the expansion of dreissenid mussels in the lake (Madenjian et al. 2010). One proposed mechanism for the increase in ninespine stickleback occurring during the dreissenid mussel expansion of the 1990s was that the concomitant increase in the prevalence of the green alga *Cladophora* improved spawning habitat quality for ninespine sticklebacks, resulting in increased ninespine stickleback recruitment. If the apparently beneficial effects of the dreissenid mussels on ninespine stickleback abundance are still operating in Lake Michigan and the importance of ninespine sticklebacks in the diet of piscivores remains very low, then we would expect ninespine stickleback abundance to increase in the upcoming years.

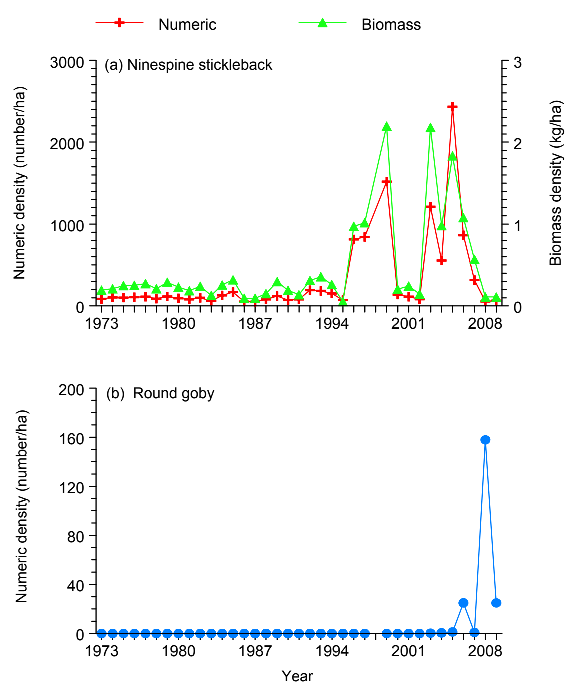

Figure 9. Panel (a) depicts numeric and biomass density of ninespine sticklebacks in Lake Michigan, 1973-2009. Panel (b) depicts numeric density of round goby in Lake Michigan, 1973-2009.

Round goby – The round goby (*Neogobius melanostomus*) is an invader from the Black and Caspian seas. Round gobies have been observed in bays and harbors of Lake Michigan since 1993, and were captured by Michigan DNR personnel in the southern main basin of the lake as early as 1997 (Clapp et al. 2001). Round gobies were not captured in the GLSC bottom trawl survey until 2003, however. By 2002, round gobies had become an integral component of yellow perch diet at nearshore sites (i.e., < 15 m depth) in southern Lake Michigan (Truemper et al. 2006). Round gobies also had become an important constituent of the diet of burbot in northern Lake Michigan by 2005 (Hensler et al. 2008; Jacobs et al. 2010).

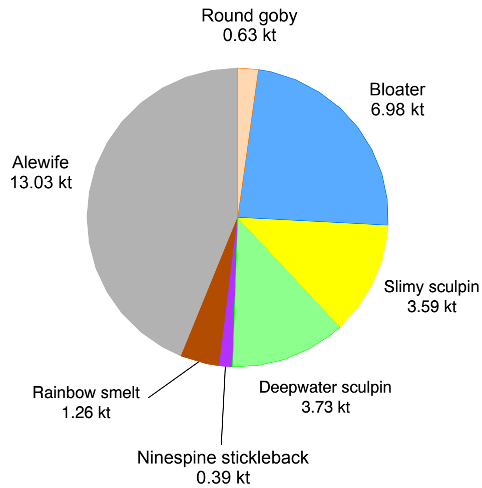

Figure 10. Estimated lake-wide (i.e., 5-114 m depth region) biomass of prey fishes in Lake Michigan, 2009, based on the bottom trawl survey.

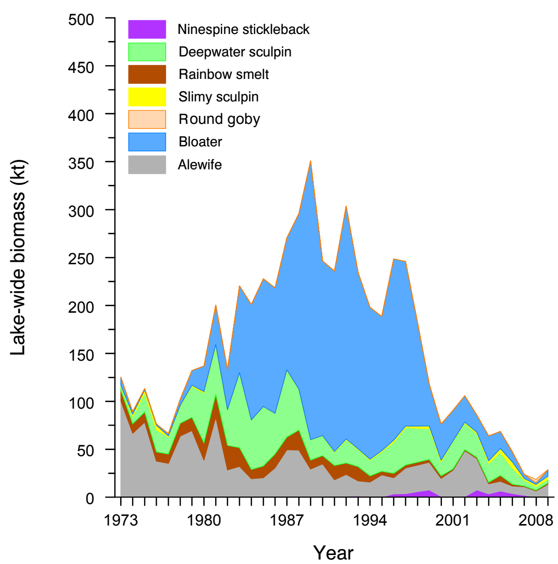

Figure 11. Estimated lake-wide (i.e., 5-114 m depth region) biomass of prey fishes in Lake Michigan, 1973-2009, based on the bottom trawl survey.

According to our bottom trawl survey, round goby numeric density has shown an overall increasing trend during 2003-2009, but with high inter-annual variability (Figure 9b). Round goby numeric density decreased from 158 fish per ha in 2008 to 25 fish per ha in 2009. Round gobies have now been captured at all transects, at depths ranging 9 to 91 m, and will likely continue to contribute to the diets of Lake Michigan piscivores into the future. Given the importance of round gobies in the diet of burbot, an offshore predator, and in the diets of yellow perch and smallmouth bass (*Micropterus dolomieu*), nearshore predators, we may expect round goby abundance in Lake Michigan to level off in the upcoming years as predatory control begins to be exerted.

LAKE-WIDE BIOMASS

We estimated a total lake-wide biomass of prey fish available to the bottom trawl in 2009 of 29.62 kilotonnes (kt) (1 kt = 1000 metric tons) (Figure 10, Appendix 1). Total prey fish biomass was the sum of the population biomass estimates for alewife, bloater, rainbow smelt, deepwater sculpin, slimy sculpin, ninespine stickleback, and round goby. Percentages of the total prey fish biomass (and biomass estimates) for the prey fish species were: alewife 44% (13.03 kt), bloater 24% (6.98 kt), deepwater sculpin 13% (3.73 kt), slimy sculpin 12% (3.59 kt), rainbow smelt 4% (1.26 kt), round goby 2% (0.63 kt), and ninespine stickleback 1% (0.39 kt).

Total prey fish biomass in Lake Michigan has trended downward since 1989 (Figure 11). This decline was largely driven by the dramatic decrease in bloater biomass. During 2002-2009, decreases in alewife and deepwater sculpin biomasses also contributed to the continued decrease in total prey fish biomass. Although total prey fish biomass in 2009 (29.62 kt) represented a 52% increase over the total prey fish biomass estimated for 2008 of 19.44 kt, the 2009 estimate of total prey fish biomass was the third lowest value in the time series; only in 2007 and 2008 was total prey fish biomass lower than that estimated for 2009.

OTHER SPECIES OF INTEREST

<u>Burbot</u> – Burbot and lake trout represent the native top predators in Lake Michigan. The decline in burbot abundance in Lake Michigan during the 1950s has been attributed to sea lamprey predation (Wells and McLain 1973). Sea lamprey control was a necessary condition for recovery of the burbot population in Lake Michigan, however Eshenroder and Burnham-Curtis (1999) proposed that a reduction in alewife abundance was an additional prerequisite for burbot recovery.

Burbot collected in the bottom trawls are typically large individuals (>350 mm TL); juvenile burbot apparently inhabit areas not covered by the bottom trawl survey.

After a period of low numeric density in the 1970s, burbot showed a strong recovery in the 1980s (Figure 12). Densities increased through 1997, and we interpret the decline between 1997 and 2002 as a leveling off in response to density-dependent forces. Burbot numeric densities had been relatively stable since 2002. Burbot numeric density decreased from 0.31 fish per ha in 2008 to 0.18 fish per ha in 2009, however burbot biomass density actually increased between 2008 and 2009. Continued surveillance will be needed to determine whether burbot abundance has begun a long-term decline.

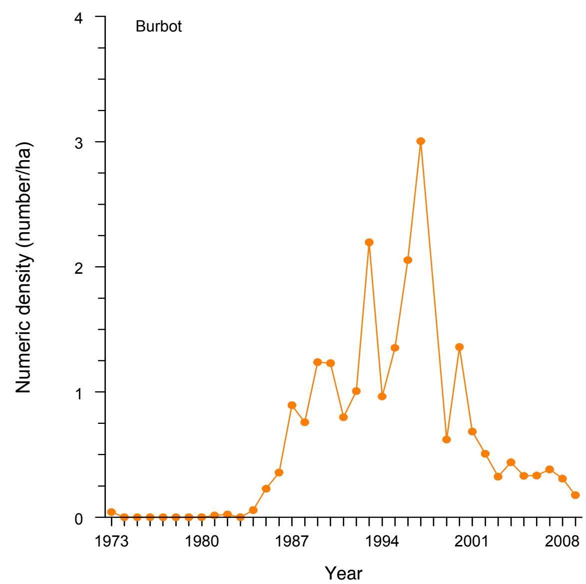

Figure 12. Numeric density of burbot in Lake Michigan, 1973-2009.

<u>Yellow perch</u> – The yellow perch population in Lake Michigan has supported valuable recreational and commercial fisheries (Wells 1977). GLSC bottom trawl surveys provide an index of age-0 yellow perch numeric density, which serves as an indication of yellow perch recruitment success. The 2005 year-class of yellow perch was the largest ever recorded (Figure 13). This huge year-class was likely attributable to a sufficient abundance of female spawners and favorable weather. Numeric density of the 2009 year-class was 38 fish per ha, an indication of a strong year-class. Unlike 2005, when relatively high age-0 yellow perch densities were observed at most transects, nearly all of the age-0 yellow perch caught during 2009 were from the Saugatuck transect. Most researchers believe that the poor yellow perch recruitment during the 1990s and early 2000s was due to a combination of several factors, including poor weather conditions and low abundance of female spawners (Makauskas and Clapp 2000).

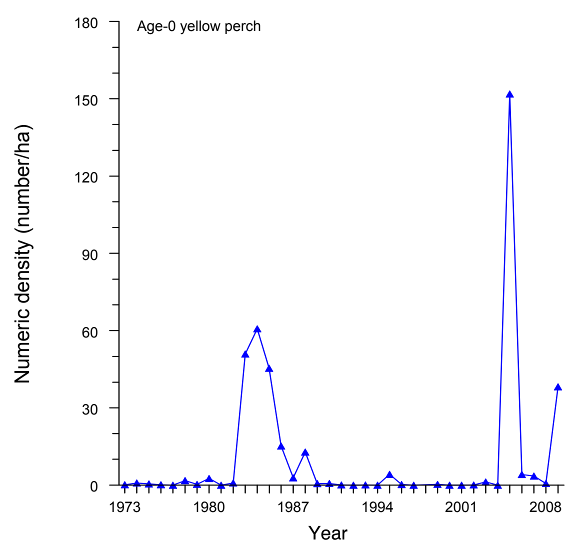

Figure 13. Numeric density of age-0 yellow perch in Lake Michigan, 1973-2009.

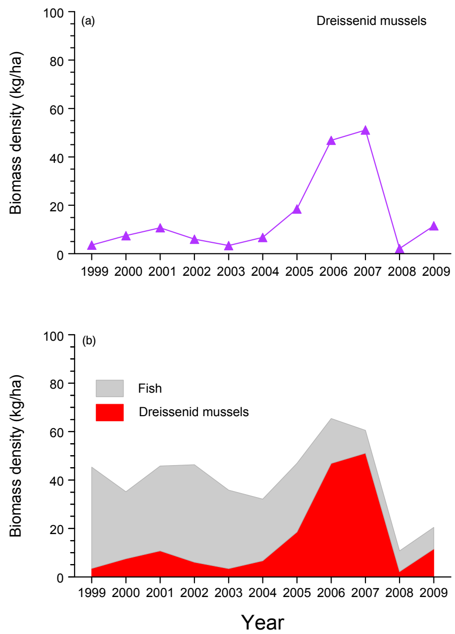

Figure 14. Panel (a) depicts biomass density of dreissenid mussels in the bottom trawl in Lake Michigan, 1999-2009. Panel (b) depicts biomass of dreissenids and total fish biomass estimated by the bottom trawl between 1999 and 2009.

Dreissenid mussels – The first zebra mussel (*Dreissena polymorpha*) noted in Lake Michigan was found in May 1988 (reported in March 1990) in Indiana Harbor at Gary, Indiana. By 1990, adult mussels had been found at multiple sites in the Chicago area, and by 1992 were reported to range along the eastern and western shoreline in the southern two-thirds of the lake, as well as in Green Bay and Grand Traverse Bay (Marsden 1992). In 1999, catches of dreissenid mussels in our bottom trawls became significant and we began recording weights from each tow. Lake Michigan dreissenid mussels include two species: the zebra mussel and the quagga mussel. The quagga mussel is a more recent invader to Lake Michigan than the zebra mussel (Nalepa et al. 2001). According to the GLSC bottom trawl survey, biomass density of dreissenid mussels was highest in 2007 (Figure 14a), which followed an exponential like increase between 2004 and 2006 (Bunnell et al. 2009b). Over this same period of dreissenid mussel increases, prey fish biomass was declining, which led to a dramatic increase in the percentage of dreissenids in the total bottom trawl catch (Figure 14b). Some authors have attributed the recent decline in prey fish to food-web changes induced by the expansion of dreissenids (Nalepa et al. 2009). In a recently published paper, however, we argued that the decline in prey fish biomass is better explained by factors other than food-web-induced effects by dreissenids, including poor fish recruitment (that preceded the mussel expansion), shifts in fish habitat, and increased fish predation by Chinook salmon (Bunnell et al. 2009b).

The biomass density of dreissenid mussels in 2009 was 11.58 kg per ha, which was equal to 23% of the peak biomass density estimated for 2007 (Figure 14a). A comparison of the biomass density of dreissenid mussels (11.58 kg per ha) with biomass density of all of the fish (8.80 kg per ha) caught in the bottom trawl indicated that 43% and 57% of the biomass in Lake Michigan during 2009 estimated from the bottom trawl survey corresponded to fish and dreissenid mussels, respectively (Figure 14b). Some of the temporal trends in dreissenid mussel biomass density shown in Figure 14a were difficult to explain. The exceptionally high biomass densities recorded in 2006 and 2007 were attributable to the expansion of quagga mussels into deeper (> 60 m) waters of Lake Michigan. However, there was no clear explanation for the drastic drop in dreissenid mussel biomass density between 2007 and 2008. According to the results of the benthic macroinvertebrate survey led by Tom Nalepa at NOAA-GLERL, quagga mussel biomass density had not yet peaked in Lake Michigan by spring 2009. Nevertheless, based on the data from Lake Erie and Lake Ontario, we would expect the quagga mussel population in Lake Michigan to eventually exceed its carrying capacity and then undergo a reduction in abundance.

CONCLUSIONS AND PROGNOSIS

Our bottom trawl estimate of total prey fish biomass in 2009 was the third lowest in our time series, which began in 1973. The relatively low prey fish biomass estimates for 2007-2009 were probably due to a suite of factors. We can clearly identify two of these factors as: (1) a prolonged period of relatively low bloater year-class strength during 1992-2009, and (2) relatively high predation on alewives by Chinook salmon during the 2000s. Assessing and quantifying the bottom-up effects on prey fish biomass will likely require additional years of surveillance, across-lake comparisons, and food-web analyses. Will the bottom trawl estimates of total prey fish biomass in Lake Michigan ever exceed 100 kt in upcoming years? The answer to this question hinges on the ability of the bloater population to show a substantial recovery in the near future. During the late 1980s and early 1990s, bloater lake-wide biomass estimates were substantially greater than 100 kt (Figure 11). A bloater recovery of sufficient magnitude would insure lake-wide biomass estimates of prey fish eventually surpassing 100 kt.

The GLFC Fish Community Objective for planktivores is not being fully achieved according to the bottom trawl survey results. The Objective calls for a lake-wide biomass of 500-800 kt, and the total prey fish biomass estimated by the bottom trawl survey was only 30 kt. The Objective also calls for a diversity of prey species. Based on Figure 10, the prey fish community is quite diverse, with four different species each contributing at least 10% to the total prey fish biomass.

REFERENCES

Argyle, R. L., G. W. Fleischer, G. L. Curtis, J. V. Adams, and R. G. Stickel. 1998. An Integrated Acoustic and Trawl Based Prey Fish Assessment Strategy for Lake Michigan. A report to the Illinois Department of Natural Resources, Indiana Department of Natural Resources, Michigan Department of Natural Resources, and Wisconsin Department of Natural Resources. U. S. Geological Survey, Biological Resources Division, Great Lakes Science Center, 1451 Green Road, Ann Arbor, MI USA.

Belonger, B. B. T. Eggold, P. Hirethota, S. Hogler, B. Horns, T. Kroeff, T. Lychwick, S. Marcquenski, P. Peters, S. Surendonk, and M. Toneys. 1998. Lake Michigan Management Reports, Wisconsin Department of Natural Resources. Lake Michigan Committee Meetings, Great Lakes Fishery Commission, Thunder Bay, Ontario, March 16-17, 1998.

Brown, E. H., Jr., and R. M. Stedman. 1995. Status of forage fish stocks in Lake Michigan, 1994. Pages 81-88 in Minutes of Great Lakes Fishery Commission, Lake Michigan Committee Meeting, Milwaukee, Wisconsin, March 29-30, 1995.

Bunnell, D. B., C. P. Madenjian, and T. E. Croley II. 2006a. Long-term trends of bloater recruitment in Lake Michigan: evidence for the effect of sex ratio. Can. J. Fish. Aquat. Sci. 63:832-844.

Bunnell, D. B., C. P. Madenjian, and R. M. Claramunt. 2006b. Long-term changes of the Lake Michigan fish community following the reduction of exotic alewife (*Alosa pseudoharengus*). Can. J. Fish. Aquat. Sci. 63: 2434-2446.

Bunnell, D. B., S. R. David, and C. P. Madenjian. 2009a. Decline in bloater fecundity in southern Lake Michigan after decline of *Diporeia*. J. Great Lakes Res. 35:45-49.

Bunnell, D. B., C. P. Madenjian, J. D. Holuszko, J. V. Adams, and J. R. P. French III. 2009b. Expansion of *Dreissena* into offshore waters of Lake Michigan and potential impacts on fish populations. J. Great Lakes Res. 35:74-80.

Bunnell, D. B., J. V. Adams, O. T. Gorman, C. P. Madenjian, S. C. Riley, E. F. Roseman, and J. S. Schaeffer. 2010. Population synchrony of a native fish across three Laurentian Great Lakes: evaluating the effects of dispersal and climate. Oecologia 162:641-651.

Clapp, D. F., P. J. Schneeberger, D. J. Jude, G. Madison, and C. Pistis. 2001. Monitoring round goby (*Neogobius melanostomus*) population expansion in eastern and northern Lake Michigan. J. Great Lakes Res. 27:335-341.

Eck, G. W., and L. Wells. 1987. Recent changes in Lake Michigan's fish community and their probable causes, with emphasis on the role of the alewife *Alosa pseudoharengus* . Can. J. Fish. Aquat. Sci. 44(Suppl. 2): 53-50.

Elliott, R. F. 1993. Feeding habits of chinook salmon in eastern Lake Michigan. M. S. Thesis, Michigan State University, East Lansing, MI. 108 pp.

Elliott, R. F., and eight coauthors. 1996. Conducting diet studies of Lake Michigan piscivores- a protocol. U.S. Fish and Wildlife Service, Fishery Resources Office, Report 96-2, Green Bay, Wisconsin.

Eshenroder, R. L. and M. K. Burnham-Curtis. 1999. Species succession and sustainability of the Great Lakes fish community. Pages 145-184 in W. W. Taylor and C. P. Ferreri (ed) Great Lakes Fisheries Policy and Management: A Binational Perspective. Michigan State University Press, East Lansing, MI.

Fleischer, G. W., C. P. Madenjian, L. M. TeWinkel, T. J. DeSorcie, and J. D. Holuszko. 1999. *Status of Prey Fish Populations in Lake Michigan, 1998*. A report to the Great Lakes Fishery Commission, Lake Michigan Committee, Milwaukee, WI, March 25, 1999.

Fratt, T. W., D. W. Coble, F. Copes, and R. E. Brusewitz. 1997. Diet of burbot in Green Bay and western Lake Michigan with comparison to other waters. J. Great Lakes Res. 23:1-10.

Hatch, R. W., P. M. Haack, and E. H. Brown, Jr. 1981. Estimation of alewife biomass in Lake Michigan, 1967-1978. Trans. Am. Fish. Soc. 110:575-584.

Hensler, S. R., D. J. Jude, and J. He. 2008. Burbot growth and diet in Lakes Michigan and Huron: an ongoing shift from native species to round gobies. Pages 91-107 in V. L. Paragamian and D. H. Bennett (ed) Burbot: Ecology, Management, and Culture. American Fisheries Society, Symposium 59, Bethesda, MD.

Jacobs, G. R., C. P. Madenjian, D. B. Bunnell, and J. D. Holuszko. 2010. Diet of lake trout and burbot in northern Lake Michigan during spring: evidence of ecological interaction. J. Great Lakes Res. 36:in press.

Jude, D. J., F. J. Tesar, S. F. DeBoe, and T. J. Miller. 1987. Diet and selection of major prey species by Lake Michigan salmonines, 1973-1982. Trans. Am. Fish. Soc. 116:677-691.

Madenjian, C. P., and D. B. Bunnell. 2008. Depth distribution dynamics of the sculpin community in Lake Michigan. Trans. Am. Fish. Soc. 137:1346-1357.

Madenjian, C. P., T. J. DeSorcie, and R. M. Stedman. 1998. Ontogenic and spatial patterns in diet and growth of lake trout from Lake Michigan. Trans. Am. Fish. Soc. 127: 236-252.

Madenjian, C. P., G. L. Fahnenstiel, T. H. Johengen, T. F. Nalepa, H. A. Vanderploeg, G. W. Fleischer, P. J. Schneeberger, D. M. Benjamin, E. B. Smith, J. R. Bence, E. S. Rutherford, D. S. Lavis, D. M. Robertson, D. J. Jude, and M. P. Ebener. 2002. Dynamics of the Lake Michigan food web, 1970-2000. Can. J. Fish. Aquat. Sci. 60:736-753.

Madenjian, C. P., J. D. Holuszko, and T. J. Desorcie. 2003. Growth and condition of alewives in Lake Michigan, 1998-2001. Trans. Am. Fish. Soc. 132:1104-1116.

Madenjian, C. P., T. O. Höök, E. S. Rutherford, D. M. Mason, T. E. Croley II, E. B. Szalai, and J. R. Bence. 2005a. Recruitment variability of alewives in Lake Michigan. Trans. Am. Fish. Soc. 134:218-230.

Madenjian, C. P., D. W. Hondorp, T. J. Desorcie, and J. D. Holuszko. 2005b. Sculpin community dynamics in Lake Michigan. J. Great Lakes Res. 31:267-276.

Madenjian, C. P., R. O'Gorman, D. B. Bunnell, R. L. Argyle, E. F. Roseman, D. M. Warner, J. D. Stockwell, and M. A. Stapanian.. 2008. Adverse effects of alewives on Laurentian Great Lakes fish communities. N. Am. J. Fish. Manage. 28:263-282.

Madenjian, C. P., D. B. Bunnell, and O. T. Gorman. 2010. Ninespine stickleback abundance in Lake Michigan increases after invasion of dreissenid mussels. Trans. Am. Fish. Soc. 139:11-20.

Makauskas, D., and D. Clapp. 2000. Status of yellow perch in Lake Michigan and Yellow Perch Task Group progress report. In Minutes of 2000 Annual Meeting of the Lake Michigan Committee. Great Lakes Fishery Commission, Ann Arbor, Michigan.

Marsden, J. E. 1992. The zebra mussel invasion. Aquaticus 23(2) 19-27.

Nalepa, T. F., D. W. Schloesser, S. A. Pothoven, D. W. Horndorp, D. L. Fanslow, M. L. Tuchman, and G. W. Fleischer. 2001. First finding of the amphipod *Echinogammarus ischmus* and the mussel *Dreissena bugensis* in Lake Michigan. J. Great Lakes Res. 27:384-391.

Nalepa, T. F., D. L. Fanslow, A. J. Foley III, G. A. Lang, B. J. Eadie, and M. A. Quigley. 2006. Continued disappearance of the benthic amphipod *Diporeia* spp. in Lake Michigan: is there evidence for food limitation? Can. J. Fish. Aquat. Sci. 63:872-890.

Nalepa, T. F., D. L. Fanslow, G. A. Lang. 2009. Transformation of the offshore benthic community in Lake Michigan: recent shift from the native amphipod *Diporeia* spp. to the invasive mussel *Dreissena rostriformis bugensis*. Freshwater Biol. 54:466-479.

Potter, R. L. and G. W. Fleischer. 1992. Reappearance of spoonhead sculpins (*Cottus ricei*) in Lake Michigan. J. Great Lakes Res. 18:755-758.

Rybicki, R.W. and D. F. Clapp. 1996. Diet of Chinook Salmon in Eastern Lake Michigan. Michigan Department of Natural Resources, Fisheries Technical Report, Ann Arbor, MI.

Smith, S. H. 1970. Species interactions of the alewife in the Great Lakes. Trans. Am. Fish. Soc. 99**:** 754-765.

Stedman, R. M., and Bowen, C. A. 1985. Introduction and spread of the threespine stickleback (*Gasterosteus aculeatus*) in lakes Huron and Michigan. J. Gt. Lakes Res. 11: 508-511.

Stewart, D. J., and M. Ibarra. 1991. Predation and production by salmonine fishes in Lake Michigan, 1978-88. Can. J. Fish. Aquat. Sci. 48:909-922.

Stewart, D. J., D. Weininger, D. V. Rottiers, and T. A. Edsall. 1983. An energetics model for lake trout, *Salvelinus namaycush*: application to the Lake Michigan population. Can. J. Fish. Aquat. Sci. 40:681-698.

Truemper, H. A., T. E. Lauer, T. S. McComish, and R. A. Edgell. 2006. Response of yellow perch diet to a changing forage base in southern Lake Michigan, 1984-2002. J. Great Lakes Res. 32:806-816.

Van Oosten, J., and H. J. Deason. 1938. The food of the lake trout (*Cristivomer namaycush*) and of the lawyer (*Lota maculosa*) of Lake Michigan. Trans. Am. Fish. Soc. 67:155-177.

Warner, D. M., C. S. Kiley, R. M. Claramunt, and D. F. Clapp. 2008. The influence of alewife year-class strength on prey selection and abundance of age-1 Chinook salmon in Lake Michigan. Trans. Am. Fish. Soc. 137:1683-1700.

Warner, D. M., R. M. Claramunt, J. D. Holuszko, and T. J. Descorcie. 2010. *Status of Pelagic Prey Fishes and Pelagic Macroinvertebrates in Lake Michigan, 1992-2009* A report to the Great Lakes Fishery Commission, Lake Michigan Committee, Windsor, Ontario, March 23, 2010.

Wells, L. 1977. Changes in yellow perch (*Perca flavescens*) populations of Lake Michigan, 1954-75. J. Fish. Res. Board Can. 34:1821-1829.

Wells, L., and A. L. McLain. 1973. Lake Michigan: man's effects on native fish stocks and other biota. Great Lakes Fishery Commission. Technical Report 20. 56 p.

Appendix 1. Mean numeric and biomass density, as well as lake-wide biomass (defined as biomass available to the bottom trawls for the region of the main basin between the 5-m and 114-m depth contours), estimates for various fishes and dreissenid mussels in Lake Michigan during 2009. Estimates are based on the bottom trawl survey. Standard error enclosed in parentheses. NA denotes that estimate is not available.

Taxon	Numeric density (fish per ha)	Biomass density (kg per ha)	Lake-wide biomass (kt)
age-0 alewife	124.65 (123.88)	0.492 (0.488)	1.731 (1.719)
adult alewife	131.85 (55.99)	3.208 (1.201)	11.299 (4.231)
age-0 bloater	29.50 (12.01)	0.221 (0.091)	0.778 (0.321)
adult bloater	72.05 (30.56)	1.762 (0.551)	6.205 (1.941)
age-0 rainbow smelt	65.54 (28.84)	0.062 (0.032)	0.220 (0.111)
adult rainbow smelt	45.22 (21.36)	0.297 (0.124)	1.045 (0.437)
deepwater sculpin	91.77 (22.71)	1.059 (0.279)	3.730 (0.981)
slimy sculpin	259.86 (62.93)	1.020 (0.237)	3.593 (0.834)
ninespine stickleback	62.90 (33.57)	0.110 (0.056)	0.388 (0.198)
burbot	0.18 (0.05)	0.255 (0.079)	0.897 (0.278)
age-0 yellow perch	38.18 (38.16)	0.066 (0.066)	0.231 (0.231)
round goby	24.97 (23.84)	0.179 (0.157)	0.632 (0.552)
dreissenid mussels	NA	11.581 (3.646)	40.785 (12.838)